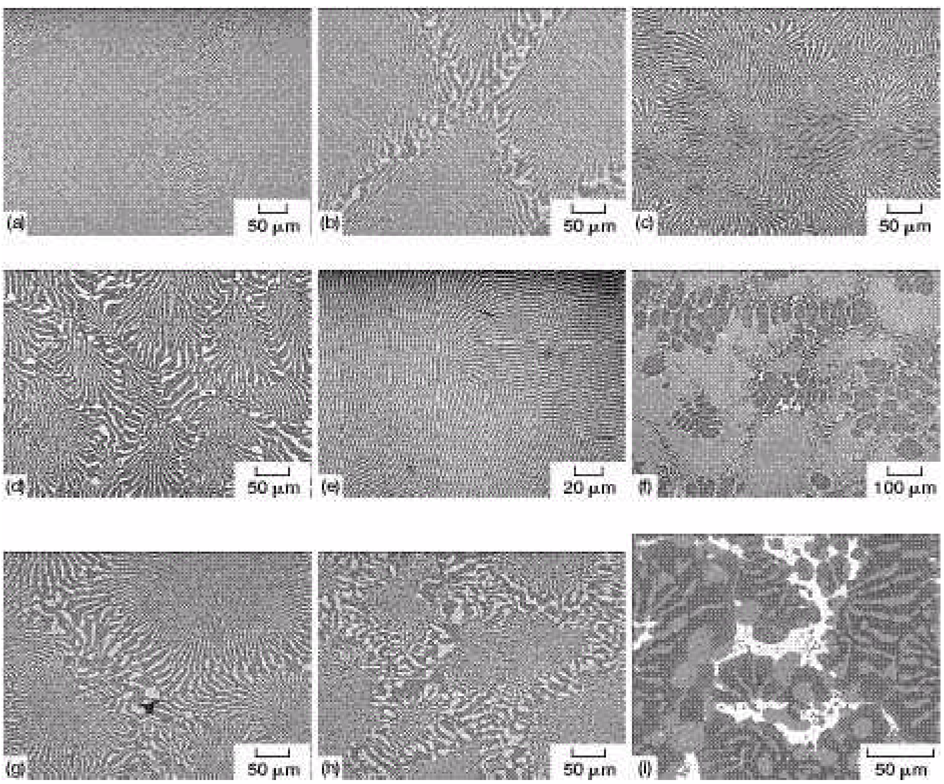
Effects of Microalloying on the Microstructures and Mechanical Properties of Directionally Solidified Ni-33(at.%)Al-31Cr-3Mo Eutectic Alloys Investigated



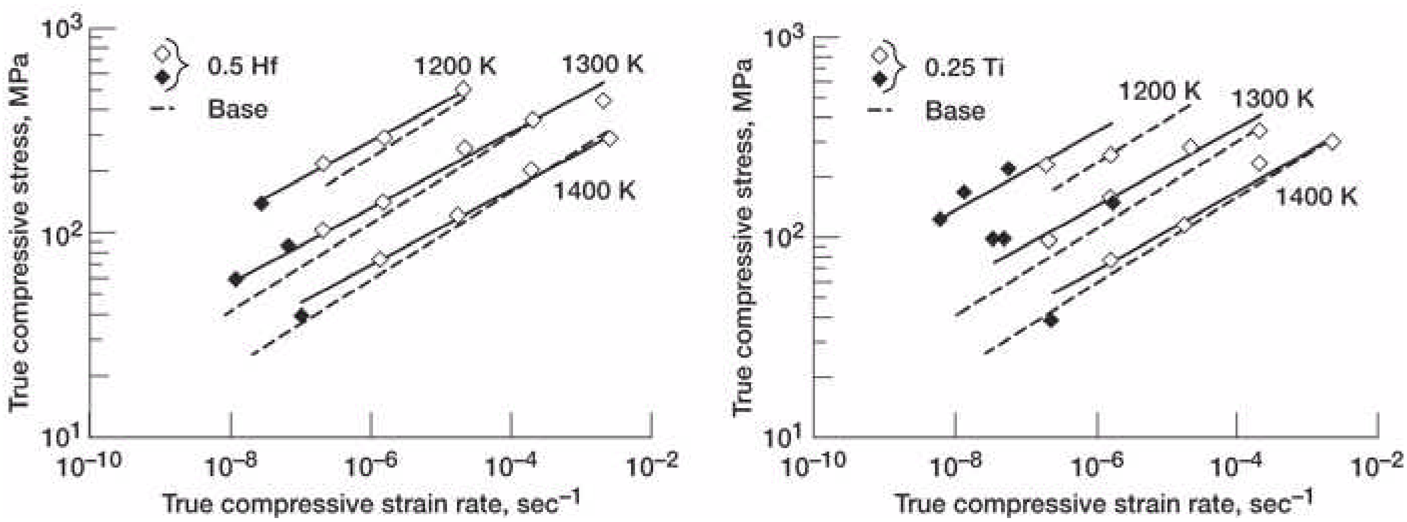
Optical (a-h) and scanning electron transverse microstructures (i) of directionally solidified Ni-33Al-(31-x)Cr-3Mo-xX alloys. (a) 0.25(at.%)Cu. (b) 0.25 Nb. (c) 0.25 Re. (d) 1.0 Re. (e) 0.5 Mn. (f) 1.0 Si. (g) 1.0 Ti. (h) 1.0 Ta. (i) 1.0 Hf. In a to h, the light phase is Cr and Mo, and the dark phase is NiAl. In (i), the white phase is Hf-rich.
Long description

Although transverse microstructures of the directionally solidified Ni-33Al-31Cr-3Mo base alloy exhibited lamellar eutectic colonies consisting of alternating NiAl and Cr,Mo plates, the addition of a fifth element resulted in the formation of a cellular microstructure. Four different types of lamellar structures were found within the cells due to the addition of these fifth elements. These include radial (a, g, and i), planar (b, e, f, and h), nautilus spiral (c), and shell (d) eutectic microstructures. The addition of 0.25 at.% Co, 0.5 to 1.0 Fe, 0.25 Hf, 0.25 to 1.0 Nb, 0.25 to 1.0 Si, and 0.25 to 1.0 Ta also resulted in the formation of NiAl dendrites (f). Additions of 0.5 to 1.0 Cu, 0.25 to 1.0 Hf, 1.0 Mn, 0.25

to 1.0 Nb, 0.5 to 1.0 Re, 0.5 to 1.0 Si, 0.25 to 1.0 Ta, 0.25 to 1.0 Ti, and 0.25 to 0.5 Zr caused the formation of broad intercellular regions (b, g, h, and i). Third phases (i) formed with the addition of 1.0 Hf, 1.0 Nb, 1.0 Ta, and 1.0 Zr.

Despite nickel aluminide (NiAl) alloys' attractive combination of oxidation and thermophysical properties, their development as replacements for superalloy airfoils in gas turbine engines has been largely limited by difficulties in developing alloys with an optimum combination of elevated-temperature creep resistance and room-temperature fracture toughness. Although single-crystal and polycrystalline NiAl alloys with superior specific creep strengths, comparable to or better than advanced superalloys, were developed by a combination of alloying and innovative processing techniques in the mid-1980's to mid-1990's, these materials had poor room-temperature fracture toughness, restricting their induction into service.

Alternatively, research has focused on developing directionally solidified NiAl-based in situ eutectic composites composed of NiAl and (Cr,Mo) phases in order to obtain a desirable combination of properties (refs. 1 to 4). Recently, it was demonstrated that the room-temperature fracture toughness K_{IC} of the directionally solidified Ni-33(at.%)Al-31Cr-3Mo two-phase eutectic alloy is about 17 MPa (ref. 5). This is a considerable improvement over that of NiAl, for which K_{IC} ~ 6 MPa. However, the elevated-temperature strength of this directionally solidified eutectic alloy is still less than that of advanced nickel-based superalloys.



Comparison of the true compressive stress - true strain rate behavior of directionally solidified Ni-33Al-31Cr-3Mo with those for eutectic alloys grown at 12.7 mm/h between 1200 and 1400 K. The open symbols represent data from constant velocity testing, whereas the solid symbols indicate constant load creep results. Left: Ni-33Al-30.5Cr-3Mo-0.5Hf. Right: Ni-33Al-30.75Cr-3Mo-0.25Ti.

Long description

The eleven alloying elements did not lead to any significant improvement in the elevated compressive strength over that of the Ni-33Al-31Cr-3Mo base alloy. However, additions of (a) 0.5 Hf and (b) 0.25 Ti showed slight improvements in the compressive strengths between 1200 and 1400 K, although the strengths of these alloys are lower than those of nickel-based superalloy single crystals.

A systematic investigation was undertaken at the NASA Glenn Research Center to examine the effects of small additions of 11 alloying elements (Co, Cu, Fe, Hf, Mn, Nb, Re, Si, Ta, Ti, and Zr) in amounts varying from 0.25 to 1.0 at.% on the elevated-temperature strength and room-temperature fracture toughness of directionally solidified Ni-33Al-31 Cr-3Mo eutectic alloy. The alloys were grown at 12.7 mm/hr, where the unalloyed eutectic base alloy exhibited a planar eutectic microstructure (ref. 4). The different microstructures that formed because of these fifth-element additions are included in the table. The additions of these elements even in small amounts resulted in the formation of cellular microstructures, and in some cases, dendrites and third phases were observed (see the preceding photomicrographs). Most of these elemental additions did not improve either the elevated-temperature strength or the room-temperature fracture toughness over that of the base alloy. However, small improvements in the compression strength were observed between 1200 and 1400 K when 0.5 at.% Hf and 0.25 at.% Ti were added to the base alloy (see the graphs). The results of this study suggest that the microalloying of Ni-33Al-31Cr-3Mo will not significantly improve either its elevated-temperature strength or its room-temperature fracture toughness. Thus, any improvements in these properties must be acquired by changing the processing conditions.

DESCRIPTION OF THE TRANSVERSE MICROSTRUCTURE IN ALIGNED REGIONS OF THE DS Ni-33Al-(31-x)Cr-3Mo-xX ALLOYS

Intended fifth element, at.%	**Lamellar eutectic grains**	**Cells**	**Cell diameter, mm**	**Cell pattern**	**NiAl dendrites**	**Intercellular regions**	**Globular NiAl in interdendritic regions**	**Distribution of fifth element**		
								NiAl	**(Cr, Mo)**	**Third phase**
0.25Co	Yes	---	---	------	Yes	---	---	Yes	---	---
0.25Cu	---	Yes	350	Radial	No	Triple points	---	---	---	---
0.5Cu	---	Yes	400	Radial	No	Yes	---	---	---	---
1.0Cu	---	Yes	250	Radial	No	Yes	Yes	Yes	---	---
0.25Fe	Yes	---	---	------	No	---	---	---	---	---
0.5Fe	Yes	---	---	------	Yes	---	---	---	---	---
1.0Fe	Yes	---	---	------	Yes	---	---	Yes	Yes	---
0.25Hf	---	Yes	200	Radial	Yes	Yes	Yes	---	---	---
0.5Hf	---	Yes	250	Radial	No	Yes	Yes	---	---	---

1.0Hf	---	Yes	200	Radial	No	Yes	Yes	Yes	---	Yes
0.25Mn	Yes	---	---	------	No	---	---	---	---	---
0.5Mn	Yes	---	---	------	No	---	---	---	---	---
1.0Mn	---	Yes	400	Radial	No	Yes	---	Not distinct	---	---
0.25Nb	---	Yes	200	Straight	Yes	Yes	Some	---	---	---
0.5Nb	---	Yes	100	Straight	Yes	Yes	Yes	---	---	---
1.0Nb	---	A few	100	Not distinct	Yes	Yes	Yes	---	Yes	Yes
0.25Re	---	Yes	200	Nautilus	No	Not distinct	---	---	---	---
0.5Re	---	Yes	150	Shell	No	Yes	Yes	---	---	---
1.0Re	---	Yes	100	Shell	No	Yes	Yes	---	Yes	---
0.25Si	Yes	---	---	Straight	Yes	---	---	---	---	---
0.5Si	---	Yes	---	Straight	Yes	Yes	---	---	---	---
1.0Si	---	Yes	---	Straight	Yes	Yes	---	---	Yes	---
0.25Ta	---	Yes	300	Straight	Yes	Yes	Yes	---	---	---
0.5Ta		Yes	200	Straight	Yes	Yes	Yes	---	---	---
1.0Ta	---	Yes	150	Straight	Yes	Yes	Yes	---	Yes	Yes
0.25Ti	---	Yes	300	Radial	No	Yes	---	---	---	---
0.5Ti	---	Yes	300	Radial	No	Yes	---	---	---	---
1.0Ti	---	Yes	300	Radial	No	Yes	Yes	Yes	---	---
0.25Zr	---	Yes	100	Shell	No	Yes	Yes	---	---	---
0.5Zr	---	Yes	100	Shell	No	Yes	Yes	---	Yes	Yes

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